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# Downy Mildew of Cucumbers

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**Downy mildew is a common and important disease of cucumbers in Massachusetts as well as in most of the eastern and southern states. This is a report on investigations of the source of the primary infection, the effect of climatic factors on the disease and on the fungus which causes it, and the prevention of infection by the use of fungicides.**

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# DOWNY MILDEW OF CUCUMBERS

By William L. Doran, Research Professor of Botany

## INTRODUCTION

Downy mildew, caused by the fungus *Peronoplasmopara cubensis* (B. & C.) Clint., is one of the most common and important diseases of field-grown cucumbers in Massachusetts. It was present here in seven out of the past eight years. In greenhouses, too, its onset is so sudden and its spread so rapid that it is regarded by growers with much concern.

The disease is by no means new, for it was present in Massachusetts as early as 1890 (21).[1] Its distribution has recently been discussed by Weber (48), and, as he points out, it has been found at some time in all regions of the United States except the more arid parts. Because of its economic importance and general distribution, this disease and the fungus which causes it have received considerable attention from earlier investigators. There is, nevertheless, much about the fungus and the disease which remains obscure.

Work described in the present paper was undertaken with the object of adding to the knowledge of host relationships, source of the primary infection, effect of climatic factors on sporulation and on spore germination and infection, and prevention of infection as by the use of fungicides.

## HOST RELATIONSHIPS

### Relative Susceptibility of the Species of Cucurbits

*Peronoplasmopara cubensis* has been reported (39, 40, 48) as occurring on 28 species of plants, all in the family Cucurbitaceae. These include cucumber, muskmelon, watermelon, squashes, pumpkin, and several gourds, ornamentals, and species not cultivated.

The species named in Table 1 were grown in the field with rows of cucumber plants alternating with rows of the other species. All plants were inoculated three times by the application of a water-suspension of the conidia of *P. cubensis* obtained from the leaves of cucumber. As was evidenced by the severity of downy mildew on cucumber, the season was very favorable to the disease, and the relative susceptibility of the several species was put to a fair test. The degrees of infection which resulted on each species in the course of the growing season are recorded in Table 1.

Downy mildew was severe on cucumber, moderate on muskmelon, present as only a trace on watermelon, and absent from squash and pumpkin. There was no infection or only a trace of infection on the other species tested.

In other fields and in several years, downy mildew has been observed causing the death of cucumber leaves when it was absent from or present as no more than a trace in adjoining plots of watermelon, summer squash, Hubbard squash, and pumpkin.

The only species of the Cucurbitaceae which grow without cultivation here are *Sicyos angulatus* and *Echinocystis lobata*. The former is rare and the latter is common. But downy mildew has not been found here on *E. lobata*, even when growing near infected cucumbers. These observations and those recorded in Table 1, like those of Clinton (10) and Halsted (18) support the conclusion of

[1] Reference is made by number to "Literature cited," p. 20.

TABLE 1.—RELATIVE SUSCEPTIBILITY OF SEVERAL SPECIES OF CUCURBITS TO INFECTION BY *P. cubensis* FROM CUCUMBER

| Species inoculated | | Degree of infection |
|---|---|---|
| *Cucumis sativus* L. | Cucumber | Very severe |
| *Cucumis sativus* L. var. *anglicus* Bailey | English forcing cucumber | Very severe |
| *Cucumis Melo* L. | Muskmelon | Moderate |
| *Cucumis Melo* L. var. *inodorus* Naud. | Cassaba melon | Moderate |
| *Cucumis Anguria* L. | Bur gherkin | None |
| *Cucurbita Pepo* L. | Field pumpkin | None |
| *Cucurbita Pepo* L. var. *condensa* Bailey | Summer squash | None |
| *Cucurbita moschata* Duchesne | Cushaw squash | None |
| *Cucurbita maxima* Duchesne | Hubbard squash | None |
| *Citrullus vulgaris* Schrad. | Watermelon | Trace |
| *Sicyos angulatus* L. | One-seeded bur cucumber | Trace |
| *Echinocystis lobata* Torr. & Gr. | Wild balsam-apple | None |
| *Luffa cylindrica* Roem. | Rag gourd | Trace |
| *Benincasa hispida* Cogn. | White gourd | Trace |
| *Lagenaria leucantha Rusby* | White-flowered gourd | Trace |
| *Trichosanthes Anguina* L. | Serpent gourd | Trace |
| *Momordica Balsamina* L. | Balsam-apple | None |
| *Melothria scabra* Naud. | | None |
| *Bryonopsis laciniosa* Naud. var. *erythrocarpa* Naud. | | Moderate |

Wilson (52) that the native species of the Cucurbitaceae are comparatively immune to downy mildew.

It seems safe to conclude that cucumbers are not in danger of infection by *P. cubensis* from wild plants in Massachusetts, and that *P. cubensis* from cucumber does not infect or does not readily infect certain other cultivated species (watermelon, pumpkin, squashes, and certain gourds) which have been reported as hosts. There is, of course, a possibility of biologic specialization by this fungus.

## Factors Affecting Susceptibility of Cucumbers

### *Varietal Differences*

Twenty-eight varieties of cucumber, including those common in the field and in greenhouses, have been grown, and downy mildew resulting from natural infection has been equally severe on all of them. The results of these observations agree with those of Clayton (9) and Weber (loc. cit.), neither of whom found any differences in the susceptibility of the varieties of cucumber to downy mildew.

### *Age of Leaves*

The oldest cucumber leaves are usually the first to be attacked by downy mildew in nature. The disease is almost never found on young leaves of cucumber and, as was observed by Halsted (17), this is true also of squash. To determine the relation of age of cucumber leaves to their susceptibility to infection by *P. cubensis*, leaves of various ages were inoculated by placing them on drops of a water-suspension of conidia. These leaves were grouped into eight classes on the basis of age. There was no infection of the three youngest leaves of any plant, and there was but little infection of the fourth leaves. Older leaves were all and equally susceptible. In these and other experiments, the youngest leaves of cucumber were entirely resistant to infection by *P. cubensis*.

According to Clinton (loc. cit.) infection may take place either through the stomata or directly through the epidermis. Stewart (42) and Selby (38), however, observed infection by the germ tubes of the zoospores of this fungus only

through the stomata, and this is the only method of infection seen by the writer. Using the xylol test of Molisch (31), it appears that the stomata of the youngest leaves of cucumbers are not open. This fact, and the relative difficulty with which such leaves are wetted, is believed to explain the resistance of young cucumber leaves.

*Fertilizers*

It has been reported (28) that applications of potassic fertilizers decrease the susceptibility of some plants to certain fungous diseases. Blattny (5) observed indications of this effect of potash, and of lime, on downy mildew of hop; and, according to Quanjer (35), downy mildews of cabbage, grape, and lettuce may be more severe in soils deficient in potassium.

In order to learn whether or not potash and lime have any effect on the susceptibility of cucumbers to downy mildew, cucumber plants were grown from seeds to the fruiting stage, in soil (an infertile and fairly acid sandy loam) treated as indicated in Table 2. The plants were grown in two-gallon crocks with treatments in triplicate. All plants were inoculated with *P. cubensis*, and the percentages of leaves which became infected within five weeks after inoculation are recorded in Table 2. The susceptibility of cucumber to downy mildew was not affected significantly by potash or lime (or a complete fertilizer) as applied to this soil.

TABLE 2.—EFFECTS OF POTASH AND LIME ON SUSCEPTIBILITY OF CUCUMBER TO DOWNY MILDEW

| Soil treatment (per acre) | Percentages of leaves infected |
|---|---|
| Check (no lime, potash, or fertilizer) | 50 |
| Potassium carbonate, 600 lbs. | 46 |
| Potassium carbonate, 1200 lbs. | 67 |
| Hydrated lime, 3 tons | 52 |
| Hydrated lime, 4 tons | 61 |
| Hydrated lime, 3 tons and potassium carbonate, 600 lbs. | 52 |
| Hydrated lime, 4 tons and potassium carbonate, 1200 lbs. | 45 |
| Complete fertilizer (5-8-7), 1500 lbs. | 42 |
| Complete fertilizer, 1500 lbs. and hydrated lime, 3 tons | 45 |
| Complete fertilizer, 1500 lbs. and hydrated lime, 4 tons | 40 |
| Complete fertilizer, 1500 lbs. and potassium carbonate, 600 lbs. | 41 |
| Complete fertilizer, 1500 lbs. and potassium carbonate, 1200 lbs. | 59 |
| Complete fertilizer, 1500 lbs., hydrated lime, 3 tons, and potassium carbonate, 600 lbs. | 49 |

## SOURCES OF THE PRIMARY INFECTION

### Search for Oospores and Other Wintering-over Stages of the Fungus in the Field

Many species of the Peronosporaceae live through the winter by means of oospores, and a number of investigators (13, 17, 21, 11, 36, 10, 4, 14) have, therefore, looked for oospores of *P. cubensis*. Rostowzew (36) is, however, the only one who believed that he found them. But he did not establish, as by their germination and infection of cucumber with them, that they were indeed oospores of this fungus.

The writer has repeatedly looked for oospores in cucumber leaves infected with or killed by *P. cubensis*. This has been done in the fall, before and after the death of the leaves, and also in the following spring and summer, after the dead diseased leaves had passed through the winter (or through two winters) buried in soil (outdoors, in a greenhouse, or in a laboratory). Oospores of one

of the Phycomycetes have occasionally, although rarely, been found by the writer in the remains of cucumber leaves, especially petioles which, after having been killed by downy mildew, had passed through one winter in the soil in the field. Efforts to germinate them or to infect cucumbers with them have, however, been unsuccessful. Thus no proof was obtained that they are oospores of *P. cubensis* or that this fungus produces oospores.

Clinton (loc. cit.) suggested the possibility that the oospores of this fungus, if there be any, may develop only after the union of distinct and sexually different mycelial strains. With this possibility in mind, the writer has inoculated the same leaves of cucumber plants with conidia of *P. cubensis* obtained from several sources. After leaves so inoculated had become infected and killed by downy mildew, they too were buried in soil over winter. The decomposed residue of such leaves was examined for oospores one and two years later, but none were found.

It is conceivably possible that this fungus might live through the winter in the soil in some other stage than as oospores, e.g., as saprophytic mycelium or specialized and long-lived conidia. None have been found, however, and no infection resulted when Clinton (loc. cit.) and Adams (2) inoculated cucurbits with soil in which cucurbits had died of downy mildew the previous season or with the remains of the leaves of cucurbits which had been killed by downy mildew.

On numerous occasions in the course of this investigation, cucumbers have been inoculated with soil in which cucumbers had grown and died of downy mildew one and two years before, or with inoculum consisting of cucumber leaves killed by downy mildew the previous fall and wintered-over in the soil outdoors. In very few cases has infection followed, and these few were always at a time of year when the conidial stage was present in the field here. It is, therefore, at least possible that such little infection as did occur was accidental rather than from inoculation with over-wintered material, and the only safe conclusion is that the results of such inoculations were negative. Thus, as in the work of other investigators mentioned above, no evidence was secured that downy mildew is associated with the over-wintering of *P. cubensis* in dead host plants here.

As supporting evidence, it should be added that there is no apparent relation between previous cropping systems and the time of appearance or severity of cucumber downy mildew. The disease often reappears in fields where it has occurred before, but the writer, like Stewart (loc. cit.), has often found it in fields in which no cucurbits had been grown for several or many years before. Adams (1) did not find any evidence that the previous crop had any relation to the prevalence of the disease; and in Florida, too, Weber (loc. cit.) has noted that crop rotation does not protect cucumbers against downy mildew.

It has been observed that the disease when it appears at all in Massachusetts, and it usually does, is to be found in every or almost every field of cucumbers, and at approximately the same time, whether or not cucumbers were previously grown in these fields. It seems evident, therefore, that the source of the inoculum may be distant and that the inoculum is probably air-borne.

In this connection, it should be noted that Adams (1) found no evidence that *P. cubensis* is seed-borne. The fungus has not been found in or on the fruit of the cucumber, and inoculations of cucumber fruits by the writer have never resulted in infection.

**Relation of the Disease in Greenhouses to the Disease in the Field**

A fall crop of cucumbers is often started in greenhouses in Massachusetts while field-grown cucumbers infected with downy mildew are still living. Under these conditions, greenhouse cucumbers frequently become infected by *P. cubensis* in the fall. The observations here recorded lead to the conclusion that such infection comes from the field rather than from the previous greenhouse crop of cucumbers. Downy mildew is not uncommon in the fall in greenhouses in which the soil has been disinfected by steaming and the air by sulfur fumigation since the last crop of cucumbers was removed. The conclusion that the fungus enters greenhouses in the fall from field-grown plants is further supported by the observation, first recorded by Stone and Smith (45), that greenhouse cucumbers started in August and September are more likely to become infected with downy mildew than are greenhouse cucumbers started later, that is, in the fall after most or all field-grown cucumbers have been killed by frost. It should also be noted that in every year from 1925 to 1930, the disease was present in Massachusetts in fields each summer and in greenhouses each fall; but there was no downy mildew in the fields here in 1931 and the disease did not appear in greenhouses here the following fall and winter.

It has been suggested (52) that *P. cubensis* lives through the winter on greenhouse cucumbers and from them is disseminated to field-grown cucumbers the next spring and summer. Observations in numerous greenhouses and in each of the past seven years lead to the conclusion that this does not often occur in Massachusetts, however. Downy mildew has usually been found here on greenhouse cucumbers in the fall, but not in the winter later than January. The observations of Stone and Monahan (44) were similar. They often found downy mildew on greenhouse cucumbers in the fall, but for seven consecutive years they learned of no case in which it was present all winter in a Massachusetts greenhouse, and in only one year did Stone (43) find the disease in greenhouses here earlier in the summer than it appeared in the field. Guba[2] too, although he has made frequent observations over a period of seven years, has not seen downy mildew on greenhouse cucumbers in Massachusetts earlier in the year than September, which is of course no earlier, in fact usually a little later, than it was also present in the field. It should be noted, however, that in one year, 1915, Osmun (33) found the disease in greenhouses in Massachusetts in May, but this was regarded as very exceptional.

The usual absence of downy mildew from greenhouse cucumbers in Massachusetts in winter and spring is explainable by the fact that in very few greenhouses in this State is that crop grown uninterruptedly throughout the winter, and by the fact that the drying effect of the heating pipes in winter is ordinarily such as to lower the humidity of the air below that necessary for the fungus. The writer has kept *P. cubensis* alive and growing on greenhouse cucumbers for 23 consecutive months, but to do this all winter it was necessary to inoculate plants at frequent intervals and to increase and maintain the humidity of the air above that which is common in winter in ordinary greenhouse practice. Whitcomb and Guba (51) have described the prevention of powdery mildew of cucumber by greenhouse management, that is, by keeping down the relative humidity of the greenhouse air. This method is no less effective against downy mildew, and the disease is a menace in greenhouses only in the fall before much artificial heat is used.

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[2]Letter of January 29, 1931 from E. F. Guba of Mass. Agr. Expt. Sta.

### Wintering-over of the Fungus in the South and Dissemination Northward by Winds

*Peronoplasmopara cubensis* is known to live through the winter in Florida. Hume (20) stated that it may be found there on living hosts throughout the year, and Weber[3] has recently informed the writer that cucurbits are grown and *P. cubensis* has been found on them in every month of the year in that State.

It has been suggested or accepted by several investigators (10, 32, 43, 14) that *P. cubensis*, living through the winter in the South, may be disseminated northward in the spring and summer with the northward advance of the season and the cultivation of the host plants.

Lacking oospores or other equally long-lived spores, the dissemination of this fungus, either locally or for greater distances, can at present be attributed only to conidia. The conidia of the downy mildew fungi are usually thought of as being very short-lived, but Angell and Hill (3) have found that the conidia of some of the downy mildew fungi (*Bremia lactucae* Regel, *Peronospora parasitica* (Pers.) de Bary, and *Peronospora hyoscyami* de Bary) may retain their viability for several days or even weeks. Similarly, Katterfield (23) found that conidia of *Peronospora schleideni* Ung. may remain viable in moist air for ten days.

The writer has succeeded in keeping the conidia of *P. cubensis* alive in moist air for 50 hours, but not longer. Spores which can live that length of time may, however, be carried long distances by the wind.

Ascending air currents may carry fungous spores, like dust, high into the air. Spores have been found floating in the air at altitudes up to 11,000 feet (41). Such spores, even at much lower altitudes may be carried horizontally many miles by wind before they settle to earth. Thus Pennington (34) found evidence that wind-borne aeciospores (of *Cronartium ribicola* Fisch.) were carried to a point 110 miles from their starting place. According to Lambert (26), there is enough movement of southerly winds to carry urediniospores of *Puccinia graminis* Pers. from Texas to the spring wheat area in the North in less than three days, and the observations of Wallace (47) lead him to the conclusion that these spores, borne north by the wind from Texas or even Mexico, may be inoculum for wheat in the Northern States.

The conidia of the downy mildew fungi are no less well adapted to distribution by wind both because of their smallness and the great numbers in which they are produced. Weston (49) observed that the spread of the Philippine Sclerosporas of maize followed closely the direction and extent of the nightly air currents. He did not attempt to determine the precise amount or extent to which the conidia of these fungi were disseminated by winds, but he found that they were carried for at least several miles and concluded that wind is the most important factor in their dissemination. Leach (27), similarly, concluded that infection of beets by *Peronospora schactii* Fckl. can often be accounted for only by wind-borne conidia.

As Lambert (loc. cit.) has pointed out, dust storm analogies and other evidence indicate that the wind is capable of carrying fungous spores many miles, or as far as from Florida to Massachusetts. But it is not necessary to postulate the flight of the conidia of *P. cubensis* the whole length of the Atlantic seaboard. Downy mildew of cucurbits is present most years, as the season advances, in most or all of the Coastal States, and it is entirely possible for the conidia to be borne from Florida to Georgia to the Carolinas and so on northward by several

[3] Letter of October 16, 1931 from G. F. Weber of Fla. Agr. Expt. Sta.

stages as the host plants are grown farther north; the absence of the disease in the North when it is already present in the South being due as much to the absence of the host as to the absence of inoculum. The evidence being, in the nature of the case, necessarily largely circumstantial, it is easier to prove that the inoculum can be carried northward by winds than that it is so carried. It is the belief of the writer, however, on the basis of the earlier discussion and the evidence presented below, that the conidia of *P. cubensis*, the primary inoculum, reach Massachusetts from Connecticut, Long Island, and the lower Hudson Valley after the fungus has reached these regions by the aid of wind from more southerly points. Because of downward air currents and rain, it seems unlikely, though possible, that the spores move the whole or nearly the whole length of the Atlantic Coast of the United States on any one wind or in any one fight. Even so, the total distance could be covered in a relatively short time, and with only short interruptions, for, as is discussed below, infection by, and incubation period and sporulation of *P. cubensis* may all occur in a few days.

In each of the seven years from 1924 to 1930 inclusive, downy mildew of cucumber has been found in the field in Massachusetts, and has always appeared within the first 18 days of August, whether the summer was rainy or dry. But the disease was not found in this State in 1931 although many cucumber fields were examined at weekly intervals, or oftener, up to the time of killing frosts. The weather of the season was not significantly different from that of previous seasons in which downy mildew had been severe, and the absence of the disease in 1931 is attributable only to lack of primary infection rather than to failure of the disease to spread within a field.

In 1931, downy mildew of cucurbits seems to have been decidedly less common and less severe south of here also.[4] In Connecticut, the disease was not found until the very end of the season and then only in one field, although the weather of the season was, in the opinion of Clinton, not unfavorable to it and it was present as usual the previous year. It was not reported as present in either New York or Pennsylvania. Only a trace of infection was found in Delaware. It was present in West Virginia, but to a lesser extent than the previous year. It was either absent or very unimportant in South Carolina. There was very little of the disease in Georgia, although the weather (rainfall) was considered favorable to it in June and July. In Florida, and this is of particular interest, fields were remarkably free from downy mildew, and the disease was not of economic importance.

There was, therefore, a minimum chance of the causal fungus reaching Massachusetts from states farther south and under these conditions, downy mildew of cucurbits did not appear in this State.

Most of the primary infection in Massachusetts occurs in August. It is at least interesting to note that in August, 1931, there were 30 per cent fewer days with southerly winds and about 39 per cent less total southerly wind movement in miles here than the averages of the preceding five years.[5] With very little inoculum in states to the south in 1931 and with much less southerly wind movement here than usual, the fungus did not appear in Massachusetts that year.

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[4]The statements in this paragraph are based on information received from G. P. Clinton, C. Chupp, G. L. Zundel, J. F. Adams, C. R. Orton, G. M. Armstrong, F. Van Haltern, and G. F. Weber, representing respectively the Agricultural Experiment Stations of Connecticut, New York, Pennsylvania, Delaware, West Virginia, South Carolina, Georgia, and Florida.

[5]This information was furnished by C. I. Gunness, Meteorologist of Mass. Agr. Expt. Sta. in letter of March 8, 1932.

## INFECTION AND SPORULATION AND THEIR RELATION TO ENVIRONMENT

A plant disease such as downy mildew of cucumber appears and spreads only when the inoculum, in this case conidia, comes in contact with susceptible host plants under conditions, as of temperature, humidity, and absence of fungicide, which are favorable to spore germination, infection, and sporulation. Spore germination, which necessarily precedes infection, will be first considered.

### Germination of the Conidia

All germination of the conidia of this fungus observed in this investigation was by zoospores, the method of germination which has been seen and described by others (21, 38, 10, 25). Rostowzew (loc. cit.) described the germination of these conidia by germ tubes, but none were seen by the writer.

Conidia germinated freely in water, including dew and water of guttation, but not in merely moist air. Unsuccessful attempts were made to germinate conidia in the diluted juices of crushed leaves of cucumber. Conidia have been seen to germinate at temperatures between 8° and 29° C., with the best germination at 16° to 19° C.

According to both Kurosawa (25) and Hiura (19), the maximum temperature for their germination is 30° C. The optimum temperature for their germination as determined by Kurosawa was 20° to 22°C., but Hiura placed it somewhat lower, at 15° to 19° C. Kurosawa concluded that the minimum temperature for their germination was 9° C., but Hiura observed some germination at 4° C. Accepting even the more narrow limits (9° to 30° C. or about 46° to 86° F.), it is evident that there is very rarely a night or early morning here in August or the first part of September (when most of the conidial germination occurs) which is too warm or too cool for some germination of these spores.

The length of time required for the germination of conidia is of interest, for the shorter this time, the less are the conidia at the mercy of a changing environment and the greater is the chance for infection. In the investigations of Clinton (loc. cit.), the conidia germinated within two to four hours after being placed in water, and as observed by Kurosawa (loc. cit.), most of the conidia germinated within one to one and one-half hours.

It was found by the writer that the time required for their germination is affected somewhat by temperature. At temperatures between 8° and 24° C., all germination was completed within three hours, but conidia germinated within two hours and thirty minutes at 12° C. and within one hour and forty minutes at 18° C.

It is concluded that two to three hours on a leaf wet with rain or dew is enough for the germination of most of the conidia of this fungus, although even conidia from the same source, and not visibly different, do not all germinate at the same time.

Conidia in the preliminary stages of germination in water were much more readily killed by subsequent exposure to dry air than were conidia which had not been previously wetted. Cucumber leaves bearing conidiophores and conidia were wetted and kept wet for fifty minutes, at the end of which time they were quickly dried for twenty minutes. Conidia thus treated were killed, while conidia which had not been previously wetted were uninjured by this short exposure to dry air (at the same temperature, 20° C.). In this way, some conidia may be killed in nature if they are on a leaf which remains wet for a short time, but not long enough to permit germination to be completed.

Zoospores emitted from germinating conidia are, as has been described by Kurosawa (loc. cit.), usually active for about one hour, following which they remain motionless for about one hour before germinating. Conidia may, therefore, under favorable conditions, emit zoospores which later initiate infection by germ tubes all within four to five hours after the conidia have reached a leaf which remains moist during that period. As is discussed below in connection with infection, it was found that there is some infection even of leaves which remain wet no longer than five hours.

The length of life of conidia was found to depend on the moisture conditions which follow sporulation. The younger the conidia, the more freely they germinated. Conidia removed from cucumber leaves and placed (on glass) in moist air at 20° to 25° C. remained viable for 50 hours, but not half so large a percentage of them germinated at the end as at the beginning of that period. In drier air, the life of the conidia was relatively short. Conidia were removed, at hourly intervals beginning at 6 a. m., from cucumber leaves wet with dew on which the fungus had sporulated in the night. Conidia removed before 10 to 11 a. m. germinated freely, but there was no germination of conidia removed later in the day after the dew had dried from the leaves in the sunlight. Similarly, germinating conidia and motile zoospores were usually found on leaves wet with dew up to about 10 a. m., but not later.

### Infection of Cucumber Leaves

Inoculum used in infection experiments was usually obtained by placing in water for two to three hours leaves on which the fungus had recently sporulated, for at the end of that time the conidia had germinated and zoospores were abundantly present in the water. Of course this method of obtaining inoculum was not used when the time necessary for infection was being investigated, since infection involves and must be preceded by germination of conidia. The high relative humidity necessary in order that inoculated plants may remain wet until infection has occurred was obtained by means of Wardian cases, or by covering plants with cloths supported on frames and kept wet with running water, or by increasing the humidity of one whole compartment of a greenhouse, which was easily possible at night and on cloudy days.

Cucumber plants growing in soil in two-gallon crocks, or shoots of plants rooted and growing in Knop's solution, were sometimes found convenient for inoculation purposes. In some cases detached cucumber leaves floated on sterile water were inoculated, but this method was not very successful. Cotyledons of cucumber seedlings were found to be easily infected on the living plants. In other cases, detached cotyledons, after being washed in sterile water, were placed in sterile Petri dishes with distilled water or a five per cent solution of glucose. These detached cotyledons were usable in inoculation experiments, for they remained alive two weeks in the sucrose solution and about three weeks in distilled water.

In order to determine how long leaves must remain wet in order to permit infection, cucumber plants were inoculated by placing on each plant 100 drops of a freshly made water-suspension of the conidia of *P. cubensis*. These plants were then placed in moisture-saturated air (at 18° C.), and after the intervals of time indicated in Table 3, some of the plants were removed to dry air for 12 hours, at the end of which time, they were returned to moisture-saturated air. The percentages of infection points which resulted, as compared with the 100 points inoculated on each plant (means for triplicates) are recorded in Table 3.

TABLE 3.—RELATION OF INFECTION OF CUCUMBERS TO LENGTH OF TIME INOCULATED PLANTS REMAIN WET.

| Number of hours inoculated plants remained wet | Percentage of points inoculated at which infection occurred |
|---|---|
| 24 | 76 |
| 14 | 71 |
| 12 | 77 |
| 10 | 82 |
| 7 | 47 |
| 6 | 22 |
| 5 | 5 |
| 2½ | 0 |

There was no infection of plants which remained wet only two and one-half hours after inoculation. Five hours on a wet leaf was enough to permit some infection, certainly enough to establish the fungus in a greenhouse or field. There was, however, much more infection of plants which remained wet six hours, and the maximum infection occurred on plants which remained wet ten hours after inoculation.

Cucumber plants which had been inoculated with a water-suspension of the conidia of *P. cubensis* were placed in moisture-saturated air at the time of inoculation. After 50 minutes, half of the plants were removed to dry air so that the foliage was entirely dry within 20 minutes. Thirty minutes later, they were returned to moisture-saturated air, with plants similarly inoculated, but not dried, and there all remained for 24 hours. No infection resulted in the case of plants which had been exposed to dry air for 30 to 50 minutes. This supports observations made in connection with the germination of conidia, to the effect that conidia which have been in water for a time may be very quickly killed by dry air, much more quickly than are conidia which have not begun to germinate.

In another series, cucumber plants were inoculated with conidia obtained early in the morning and at intervals of one hour from plants wet with dew in the field. Infection resulted up to the time that the sun dried the dew from the leaves from which conidia were obtained, but not later. It appears from this that infection in nature, in sunny weather and the absence of rain, takes place the same night or the same morning as that in which sporulation has brought the infecting conidia into existence. The same dew or rain (or water of guttation) which induces sporulation may also provide the necessary moisture for germination and infection. This is one reason why downy mildew often spreads so rapidly in the field.

Rain is unnecessary for infection by *P. cubensis*. Dew or water of guttation often provides all the moisture on the leaf which is necessary for infection. As has been noted by Clayton (9) and others, downy mildew of cucumber may be severe even in dry seasons.

When soil and air are sufficiently moist, as they sometimes are in greenhouses in the fall before artificial heating is used, water of guttation escapes from and collects on the margins of the leaves of cucumbers. An examination of cucumber leaves naturally infected in a greenhouse showed that more than half of the first infection occurred on the margins of the leaves. In order to investigate the part which water of guttation may play in infection, cucumber plants were inoculated by placing dry conidia on the dry leaves. Plants thus inoculated were grown in soil maintained at 70 to 75 per cent of its water-holding capacity

and in air with a relative humidity of not less than 90 per cent at about 20° C. Under these conditions, drops of water of guttation soon appeared on the margins of the leaves. A good infection, including sporulation, resulted, and it was confined to the margins of the leaves where the water of guttation had stood, although conidia had been applied all over the surface of the leaves. No infection resulted when cucumber plants were thus inoculated by placing dry conidia on dry leaves if the inoculated plants were then grown in soil and air too dry for water of guttation to appear.

The relation of air temperature to infection of cucumber by *P. cubensis* has been investigated by Hiura (loc. cit.) who concluded that the minimum temperature for infection is 10° to 15° C., the optimum about 20° C., and the maximum at or not far above 30° C. The writer has secured infection of cucumber plants inoculated at 10°C., but not below, and at 28° C., but not above; most complete infection has been secured at temperatures between 16° and 22° C. These temperatures at which infection is possible correspond fairly closely to the cardinal temperatures for the germination of conidia, to which reference has already been made.

Infection through upper as compared with lower surfaces of the leaves is of interest, as having a possible bearing on the use of fungicides. The observations of the writer lead him to agree with earlier investigators (38, 42) that infection by the germ tubes of the zoospores of this fungus is through the stomata. However, as has been recorded by others (38, 16), cucumber plants may be infected by this fungus through both the upper and lower leaf surfaces. As determined by the writer, there are two to three times as many stomata per unit area on the lower surface as on the upper surface of cucumber leaves, but there is abundant opportunity for infection through both surfaces except as they are protected by fungicides. In fact, it is probable that more leaves are infected through the upper surface, for the writer was able to prevent most (but not all) accidental infection by applying a fungicide to the upper surfaces of leaves, but not the lower.

The incubation period for downy mildew of cucumber may mean either the interval of time between inoculation and sporulation, that is, the appearance of conidiophores and conidia on inoculated leaves, or it may mean the interval of time between inoculation and the appearance of the yellowish leaf spots indicative of infection. These leaf spots usually appear three to five days after inoculation. With temperature and moisture conditions near the optimum, infection of leaves usually ends in sporulation within six to nine days after inoculation. In the case of cotyledons of cucumber seedlings, the incubation period may be shorter, so that conidiophores and conidia are produced four to six days after inoculation. If the incubation period is understood to end only with sporulation, it may, as is described below, be prolonged in dry air almost indefinitely, within the life of the plant of course. Even in moist air, the incubation period is affected somewhat by temperature. The incubation period ended in sporulation seven days after inoculation at 20° to 28° C. and nine days after inoculation at 16° to 20° C.

These results may help to explain the observation of Hiura (loc. cit.) who noted that the appearance of the disease in the field was hastened by high temperatures up to 30° C., and delayed by low temperatures near the minimum for infection.

### Sporulation

Conidiophores and conidia of this fungus were found growing only on the true under side of leaves. This was the case even when leaves of cucumber were inoculated only on the upper surface, or when infected leaves were kept wet only on the upper surface, or when petioles of inoculated leaves were so twisted as to hold the leaves inverted. According to Rostowzew (loc. cit.), however, *P. cubensis* may sporulate, although rarely, on the upper surface of leaves. In the course of this investigation, cotyledons of cucumber seedlings were often inoculated and on them the fungus sporulated on both upper and lower surfaces, although the cotyledons, like leaves, have typical palisade cells above with spongy mesophyll below. In this, the behavior of the fungus is like that of *Peronospora schachtii*, for Leach (loc. cit.) observed that the latter produced conidiophores only on the lower surface of the leaves of beets, but on both the upper and lower surfaces of cotyledons.

Good and equally complete sporulation was obtained at air temperatures between 16° and 22° C. The cardinal temperatures for the production of the conidia of this fungus as determined by Hiura (loc. cit.) are: maximum, 27° C.; optimum, 15° to 19° C.; and minimum, below 10° C. This is the same as his optimum temperature for the germination of conidia, but his maximum for sporulation is a little lower than for germination. In either case the range is great enough so that there is little likelihood of the disease being much checked by temperature in the field here.

Sporulation, as observed in the field, occurred most freely in the early morning on leaves then wet with dew. Rain is not necessary for sporulation. The moisture of dew permits and induces sporulation, germination, and infection, all within a few hours, ending with the drying of the dew by the sun in the course of the forenoon. In this, *P. cubensis* resembles *Sclerospora graminicola* (Sacc.) Schroet., for Weston (50) found that dew provides enough moisture for the production of conidia by that fungus. Van Everdingen (46) has similarly emphasized the importance of dew in favoring outbreaks of potato late blight.

As has been mentioned in connection with the incubation period, *P. cubensis* may live in inoculated leaves in dry air for several days or weeks without sporulating. Leaf spots appear, often rectangular and at first limited by small veins, but the violet or purplish-gray mats of conidiophores and conidia do not develop on them nor do the spots increase in size until the relative humidity of the air is raised almost to saturation. In long-continued dry weather, the tissue in these leaf spots and the fungus with them may die without the whole leaf being killed.[6] However, if the air becomes sufficiently moist before this occurs, sporulation follows very promptly. Cucumber plants inoculated with *P. cubensis* were allowed to remain in moist chambers, at 20° C., for two days following inoculation, at the end of which time they were placed in the dry air of a laboratory where they remained for three weeks. Leaf spots indicative of infection appeared on them six days after inoculation, but no conidiophores were produced in the course of three weeks in the dry air. At the end of this time, the foliage was wetted, the plants were placed in the moisture-saturated air of Wardian cases, and an abundant growth of conidiophores resulted within twelve hours.

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[6] It is not unlikely that the drouth of 1930 was in this way the cause of the limited inoculum in the South the following year, to which reference has already been made.

## EFFECTS OF FUNGICIDES ON SPORULATION, GERMINATION, AND INFECTION, AND ON CUCUMBER PLANTS

### Effects of Sulfur and of Copper-lime Dust on Sporulation

The effectiveness of fungicides against the downy mildews and many other fungi is usually explainable by the fact that they are toxic to the spores of fungi and thus prevent spore germination and infection. Relatively little attention has been paid to the effect of fungicides on the sporulation of such fungi.

Cucumber plants which had been inoculated, but on which the fungus had not as yet sporulated, were wetted and dusted either with sulfur or with copper-lime dust.[7] These plants were then placed in moist chambers together with other inoculated plants with the disease in the same stage of incubation, but without fungicides. The fungus sporulated normally on the leaves of plants without fungicides. There was some, but less sporulation on leaves of plants with copper dust. There was no sporulation on leaves of plants which had been dusted with sulfur.

In later experiments, detached cucumber leaves, showing the leaf spots symptomatic of infection by *P. cubensis*, but with no sporulation of the fungus, were wetted and divided into three groups of 50 leaves each. One lot was dusted with sulfur, one with copper-lime dust, and one received no fungicide. All were kept over night in a moist chamber at 18° C. and then examined for sporulation. Per unit area of leaf surface, conidia present expressed as relative numbers were as follows: on leaves without fungicide, 100; on leaves with copper-lime dust, 29 to 80; on leaves with sulfur dust, 0 to 5.

In these experiments, therefore, sulfur was much more effective than copper-lime dust in preventing sporulation. Some of the effect of sulfur on this fungus and the disease which it causes is due to its action in inhibiting sporulation, but it is evident that this effect alone is not enough to prevent infection of plants by a fungus the spores of which may be wind-borne from other plants which have not been sulfured, unless the fungicide is also effective in preventing spore germination. Such prevention of sporulation can prevent later infection only when there is no other source of inoculum from plants not sulfured, which may be the case in greenhouses here in fall and winter after all field-grown cucumbers have been killed by frost. This may explain in part the observation of Stone (43) that sulfur vaporized on heating pipes at least helps to prevent downy mildew of cucumber in greenhouses.

### Effect of Sulfur on the Germination of the Conidia

Cucumber leaves infected with *P. cubensis* and bearing the conidiophores and conidia of this fungus were cut in half, and half of each leaf was dusted with sulfur. These and the unsulfured halves of the leaves, in neither case wetted, were placed in moist chambers (Wardian cases) at temperatures from 22° to 26° C. After intervals of time varying from 1¼ to 5 hours, conidia were removed and placed in water at a temperature of 18° C. Under these conditions, more than 60 per cent of the conidia from leaves not sulfured germinated. The percentage of sulfured conidia which germinated is shown in Table 4.

Exposure to sulfur for 5 hours at 22° C. or for 4½ hours at 24° C., with the sulfur in contact with the conidia and without precipitated moisture, prevented the later germination of these conidia.

[7] The sulfur used in these and later experiments was 300-mesh (98 per cent) dusting sulfur, and the copper-lime dust was one guaranteed to contain not less than 19 per cent monohydrated copper sulfate.

TABLE 4.—EFFECT OF SULFUR ON GERMINATION OF CONIDIA

| Conditions of exposure to sulfur (dry) | | Percentage of conidia which germinated when placed in water. |
|---|---|---|
| Temperature (°C.) | Time (hours) | |
| 26 | 1¼ | 50 |
| 26 | 2¾ | 22 |
| 26 | 4 | 7 |
| 26 | 4½ | 0 |
| 24 | 4½ | 0 |
| 22 | 5 | 0 |

For purposes of comparison, other downy mildew fungi were similarly used. It was found that the conidia of *Bremia lactucae* were killed by contact with dry sulfur for 6 hours at 23° C. and the conidia of *Peronospora effusa* (Grev.) Ces. were killed by contact with dry sulfur for 4½ hours at 26° C. Both Erwin (12) and Guba[3] have found that the conidia of *Bremia lactucae* may also be killed by exposure to vaporized sulfur.

Sulfur was toxic to the conidia of *P. cubensis* when applied dry as above described, but it was found to be non-toxic to them when they were in water. The conidia germinated freely when placed in water on micro-slides or leaves which had been dusted with sulfur. Kendrick (24) noted the same lack of effect of sulfur on the germination of the conidia of *Bremia lactucae* when they were placed in drops of water on a surface which had been dusted with sulfur. Copper-lime dust on the other hand was found by the writer to prevent the germination of the conidia of *P. cubensis* when used in water this way.

The water necessary for the germination of these conidia does not interfere with the fungicidal action of copper, but it prevents the toxic action of sulfur, at least to *P. cubensis* and to *B. lactucae*. This is naturally a very serious limitation to the value of sulfur for use against downy mildew of cucumber (and of lettuce), for it is least effective under conditions when it is most needed, that is, when there is water on the leaves. Sulfur does, however, have some slight fungicidal value against downy mildew of cucumber, as Weber (loc. cit.) concluded from his field experiments. This is attributable to its effects on the conidia in the absence of water, and on sporulation.

## Protection of Cucumber against Downy Mildew by Sulfur and by Copper Fungicides

Sulfur is often used in the greenhouses of Massachusetts to control powdery mildew of cucumber, as recommended by Guba (15). The extent to which sulfur may also be effective, especially as compared with copper fungicides, in protecting cucumbers against downy mildew was, therefore, further investigated.

Infected cucumber leaves on which the fungus was sporulating were dusted with sulfur. These leaves and similar leaves not sulfured were placed in moist chambers at 25° C. for 4½ hours. Conidia were then washed from them and used to inoculate cucumber plants. Thirty drops of a suspension of sulfured conidia were placed on each of 20 plants, and conidia which had not been sulfured were applied in the same way to 20 other plants. Seven days later, there was an

[3]Guba, E. F. 1928. Mildew of lettuce. Jour. Market Garden Field Sta. of Mass. Agr. College, No. 95:4-5. (Mimeographed.)

average of 24 infection points per plant on the plants inoculated with conidia not sulfured, but there was no infection of plants inoculated with sulfured conidia. In a similar experiment, lettuce plants were inoculated with conidia of *Bremia lactucae* which had been in contact with sulfur (dry) for 6 hours at 23° C. No infection resulted, although there was abundant infection of lettuce inoculated with conidia from the same source but not exposed to sulfur. In these experiments, there was no water on the leaves when the sulfur came in contact with conidia.

In other experiments, leaves of cucumber plants were dusted with sulfur, and drops of water containing conidia of *P. cubensis* were placed on them. Under these conditions, infection was not prevented. As before, the behavior of *P. cubensis* in this respect was compared with that of another downy mildew fungus. Drops of a water-suspension of the conidia of *Bremia lactucae* were placed on lettuce plants after the plants had been dusted with sulfur, and under these conditions normal infection resulted. Copper-lime dust similarly used prevented all infection by both of these fungi.

In these and other experiments, partial protection of cucumbers was thus afforded by sulfur if the inoculum, conidia of *P. cubensis*, was made ineffective by the sulfur before the inoculum in water was present on a leaf. But if the conidia were in water on a leaf before the sulfur reached them, their germination and the resulting infection were not prevented. It seems evident that more reliance may be placed on sulfur for the control of downy mildew of cucumber in the greenhouse than in the field. It is true that in the greenhouse, leaves of cucumber may be wet at times (as by leaks, overhead watering, or water of guttation) and under these conditions, sulfur will not be effective; but in the field, leaves and conidia may be wet every dewy morning and under these conditions, sulfur is ineffective. It is then that copper fungicides are most valuable.

Earlier investigators are practically agreed that downy mildew of cucurbits as it occurs in the field, is profitably controllable by Bordeaux mixtures. Their conclusions have recently been cited by Weber (loc. cit.) and will not be reviewed here. Adams[9] and Weber (loc. cit.) have also found copper-lime dusts effective.

In experiments by the writer, sulfur and copper-lime dusts were applied to cucumbers in the field at intervals of 8 days beginning both before and after infection by *P. cubensis* (2 days after the first conidiophores were found on the leaves.) Plots dusted first before infection received two more applications than did plots dusted first after infection. Each plot was 10 feet wide and 100 feet long and plots were in triplicate. Average yields in pounds per unit area, expressed in relative numbers, are recorded in Table 5 for the years 1926 and 1927.

Sulfur did not increase yields, in fact its use was followed by yields lower than those of check plots. This means that sulfur not only failed to provide protection, but actually injured the cucumber plants to which it was applied. Plots which received early applications of sulfur did, however, yield more than plots first dusted with sulfur after the disease appeared, indicating that sulfur had some fungicidal effect, although not enough to offset its toxicity to the dusted plants.

Other investigators (53, 29, 15, 48) have also found that sulfur may be injurious to cucumbers and other cucurbits, especially muskmelon. Because of the susceptibility of greenhouse cucumbers to injury by sulfur if applied too

[9]Adams, J. F. Downy mildew caused by *Pseudoperonospora cubensis*. U. S. Dept. Agr., Bur. Plant Ind., Plant Dis. Rptr., Sup. 34, pp. 202-203. 1924. (Mimeographed.)

TABLE 5.—EFFECTS OF SULFUR AND COPPER-LIME DUST ON YIELDS OF CUCUMBERS INFECTED WITH *P. Cubensis*

| Plot treatments | YIELDS (expressed as percentages) | |
|---|---|---|
| | In 1926 | In 1927 |
| Check, no fungicide | 100 | 100 |
| Sulfur dust, applications begun after first infection | ..... | 70 |
| Sulfur dust, applications begun before first infection | ..... | 94 |
| Copper-lime dust, applications begun after first infection | 102 | 157 |
| Copper-lime dust, applications begun before first infection | 168 | 197 |

heavily, Guba (loc. cit.) concluded that not more than 6 pounds of sulfur dust should be applied in a cucumber greenhouse 280 by 40 feet (for the control of powdery mildew). The same caution is suggested whenever greenhouse cucumbers are dusted with sulfur for any reason.

The dusting of greenhouse cucumbers with sulfur for the control of powdery mildew may, as discussed above, help to protect them against downy mildew also; but a copper fungicide, a Bordeaux mixture, is preferable if only downy mildew is to be combated. In the experiments of the writer, as in those in California[10] and Florida (48), sulfur did not satisfactorily control downy mildew of cucurbits under conditions favorable to the fungus, and similar results when sulfur was used were secured by Clayton (8) with downy mildew of lima bean, by Boyd (6) with late blight of potato, by Salmon and Ware (37) with downy mildew of hop, and in California (30) with downy mildew of lettuce. We may conclude that although sulfur is, of course, and generally, a valuable fungicide, this is probably not the case when downy mildews are to be combated.

In the field experiments, the results of which are summarized in Table 5, yields of cucumbers in 1927 were increased 97 per cent by copper-lime dust when the first applications were made before infection by *P. cubensis*, but only 57 per cent when the first applications were made after infection. Similar results were obtained the previous year, 1926, when yields were increased 68 per cent by copper-lime dust applied first before infection and only 2 per cent, or not significantly, when this treatment was first applied after infection. These results support the conclusions or recommendations of most earlier investigators (10, 42, 32, 48, 22, 7) to the effect that for maximum protection of cucurbits against downy mildew, it is necessary that fungicides be applied before rather than after infection.

*Date of Beginning Applications*

As has been observed by a number of investigators (9) (48, 42, 15), it is, however, quite possible to injure cucumber plants with Bordeaux mixture, and Clayton (9) and Zimmerly and co-workers (54) have found that young plants of cucumber and canteloupe, respectively, are more susceptible to such injury than are older plants. We may conclude that although cucumbers should be sprayed or dusted with a copper fungicide before infection, the first applications should not be made unnecessarily early. It is, therefore, important to know the approximate date at which the disease usually appears in the field in a given locality.

[10]U. S. Dept. Agr., Bur. Plant Ind. Diseases of field and garden crops in the United States in 1919. U. S. Dept. Agr., Bur. Plant Ind., Plant Dis. Rptr., Sup. 10, pp. 180-273. 1920. (Mimeographed.)

In each of the six years from 1925 to 1930 inclusive, downy mildew was looked for in cucumber fields of Hampshire County, Massachusetts, at intervals of 3 days beginning July 20 and continuing until the disease appeared. Downy mildew was first found here on August 15 in 1925, August 4 in 1926, August 6 in 1927, August 9 in 1928, August 18 in 1929, and August 11 in 1930. For six years, therefore, the disease always appeared here for the first time between August 4 and August 18, and this without any apparent relation to the date of planting or the weather of the season. On the basis of these observations, it is probable that field-grown cucumbers here need to receive treatment with a copper fungicide for protection against downy mildew beginning about July 25, but not before.

*Frequency of Applications*

The intervals of time between applications of a fungicide to plants are usually determined by the rate at which the plants grow and the rapidity with which the material is lost from the leaves as by weathering. It is frequently recommended that fungicides be applied "often enough to keep new growth covered." However, as has been shown, the youngest leaves of cucumber do not become infected with downy mildew, although these temporarily resistant leaves become susceptible as they grow older. *P. cubensis* is, under favorable environmental conditions, reproduced and disseminated very rapidly. On August 5, 1926, downy mildew was found on less than 2 per cent of the cucumber plants in a field of about 1 acre; on August 10 it was present on a little more than 50 per cent of the plants; and on August 15 every plant in the field was infected. It is evident that the intervals of time between applications of fungicides in such cases should not be long. Clayton (9) recommended that fungicides be applied to cucumbers in the field twice a week. In Massachusetts, however, adequate protection has been obtained with a copper fungicide applied 5 times at intervals of 8 days; and the disease was profitably prevented by Weber (loc. cit.) when applications of Bordeaux mixture or of copper-lime dust were applied at intervals of 1 week. This is considered to be often enough in this State.

*Concentration of Bordeaux Necessary*

Downy mildew of cucumber was controlled in the field by Bordeaux mixture 3:3:50 without injury to plants, and that is the concentration here recommended for use in the field. There may, however, be severe injury and stunting of the foliage of greenhouse cucumbers sprayed with Bordeaux mixture of this formula.

Many fungicides as used in the field are applied at a greater concentration than is actually required to prevent spore germination and infection. This practice may be necessary in the field, however, because of the gradual loss or removal of the effective constituent by rains or weathering. In greenhouses, the likelihood of such loss is at a minimum. With this consideration in mind, and because of the possibility of injury to greenhouse cucumbers by copper fungicides, the effects of each of several Bordeaux mixtures on infection of greenhouse cucumbers by *P. cubensis* was investigated.

Greenhouse cucumber plants (30 plants receiving the same treatment) were sprayed 3 times at intervals of 1 week using Bordeaux mixtures of the following formulas: 3:3:50, 3:10:50, 2:2:50, 2:10:50, or 1:1:50. Although there was in this case no real burning of foliage, the growth of plants sprayed with Bordeaux mixtures containing more than 0.25 per cent copper sulfate was retarded. All plants (including checks) were inoculated with *P. cubensis* 2 days after the

second application of fungicides. Every leaf of check plants without fungicide became infected. There was no infection of any of the plants sprayed with any of the Bordeaux mixtures, including the 1:1:50 formula. In these and other experiments of the writer, infection of greenhouse cucumbers by *P. cubensis* was prevented by Bordeaux mixture 1:1:50, and in these experiments, as in those of Guba (15), Bordeaux mixture 1:1:50 did not have the injurious effect on leaves of greenhouse cucumbers which sometimes follows the use of Bordeaux mixtures containing more copper. It is concluded that a Bordeaux mixture of the 1:1:50 formula is to be preferred to a more concentrated mixture when a fungicide is needed for the control of downy mildew of cucumber in greenhouses.

## SUMMARY

Downy mildew caused by *Peronoplasmopara cubensis* is common and often severe on all varieties of cucumbers in both fields and greenhouses here. The fungus from cucumber was found to infect muskmelon, but not squashes, pumpkin, or watermelon. Cucumber is in no danger of infection by this fungus from weed hosts in this State. Youngest leaves of cucumber were found to be resistant to infection. The susceptibility of cucumber was not affected by applications of potash or lime to the soil.

No oospores or other wintering-over stages of the fungus have been found here, and inoculation of plants with material wintered-over in the soil has not resulted in infection. There is no relation between previous cropping systems and the occurrence of the disease here. The fungus enters greenhouses from fields in summer and fall, but it very rarely lives through the winter in greenhouses in Massachusetts. The fungus lives through the winter on living hosts in the South. All available evidence indicates that the fungus probably reaches Massachusetts from states farther south after a gradual northward movement by the aid of wind.

Conidia germinate in water, including dew and water of guttation. They were found to germinate at temperatures from 9° to 30° C. and to germinate best at 16° to 19° C. Infection took place at temperatures from 10° to 28° C. with most complete infection at 16° to 22° C. which was also about the optimum temperature for sporulation. Two to three hours on a wet leaf is long enough for germination. Conidia may emit zoospores and these may initiate infection, all within 5 hours. Length of life of conidia depends on moisture conditions. Some conidia remained viable for 50 hours in moist air.

Leaves which remained wet only 2½ hours were not infected, but there was some infection of leaves which remained wet 5 hours after inoculation.

Infection usually ends in sporulation within 6 to 9 days after inoculaton. Dew may provide enough moisture for sporulation. In dry air, the fungus may live in infected leaves for several weeks without sporulating.

Sulfur was more effective than copper-lime dust in preventing sporulation of the fungus. Conidia were killed by contact with dry sulfur for 5 hours at 22° C. Sulfur was, however, not toxic to these conidia in water. Infection was not prevented when the conidia in water fell upon leaves dusted with sulfur. Not only did sulfur fail to provide protection in the field, but it was also definitely injurious to cucumber plants. In both field and greenhouse copper fungicides are to be preferred to sulfur for the control of downy mildew.

Yields of cucumbers were increased more if copper-lime dust was first applied before, rather than after, infection. In Massachusetts, the first application of a copper fungicide should be made, in the field, about July 25. Later applications should be made at weekly intervals. Bordeaux mixture 3:3:50 is a sufficient concentration for use in the field. Bordeaux mixture 1:1:50 prevented infection of greenhouse cucumbers and, because of the possibility of copper injury, this is the concentration suggested for use in greenhouses.

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